NASA

Technical Memorandum 82149

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(NASA-TM-82149) THE 805S X-RAY PULSAR H2252-035 (NASA) 16 p HC A02/MF A01 CSCL 03B

N81-29060

Unclas

G3/93 31115

JUNE 1981

National Aeronautics and
Space Administration

Goddard Space Flight Center
Greenbelt, Maryland 20771

THE 805s X-RAY PULSAR H2252-035

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ABSTRACT

We demonstrate that the X-ray flux from the 3.6 hr binary system H2252-035 is modulated at a period of 805s. The spectrum is consistent with either a 1.4 photon index power law or > 20 keV thermal model. A 560 ± 350 eV equivalent width iron line is seen at ~ 6.7 keV. We discuss the possibility that this system contains a slowly rotating neutron star.

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I. INTRODUCTION

The 13th magnitude optical counterpart to the X-ray source H2252-035 (Griffiths et al. 1980, Marshall et al. 1979) was discovered to be modulated with two periods, 858s (Warner 1980, Patterson and Price 1980) and 3.6 hrs (Patterson and Price 1980) with semi-amplitudes of 5 and 10% respectively. Subsequent analysis of HEAO A2 data revealed that the X-ray flux was also modulated, but not at either of the optical periods, rather at a third period of 805s (White and Marshall 1980). This somewhat surprising result was simply resolved by the observation that the X-ray period is a beat between the two optical periods. The optical pulsations most likely come from X-ray pulsations reprocessed in material that is orbiting about the X-ray pulsar with a period of 3.6 hrs. The optical pulse period is down shifted because the orbiting material sees one less pulse per orbital period than a stationary observer (for prograde rotation of the pulsar). Further analysis has now revealed that the X-ray period of 805s is also present in the optical data at the 2% level (Warner and Donoghue 1980; Patterson and Jablonski 1981). The optical emission lines show sinusoidal variations of amplitude 145 km s^{-1} commensurate with the orbital period, with maximum velocity away from the observer occurring one quarter of an orbital period after maximum light (Patterson and Price 1981). The optical continuum from 1200-22000 Å is best represented by a 12,500 K blackbody, but with IR and UV excesses (Hassall et al. 1981).

Models for H2252-035 have been based on the concept that this system is fundamentally similar to cataclysimic variables i.e. it is a 3.6 hr binary system containing a compact object accreting material, via a disk, from a Roche limited low mass star. Two different reprocessing sites have been suggested to account for the 858 s optical pulsations. Patterson and Price

(1981) discuss, perhaps the most obvious location, the face of the companion star, while Hassall et al. favor a more exotic model wherein the reprocessing takes place at a bulge in the accretion disk, corresponding to the point where inflowing material feeds into it. Because the optical to X-ray luminosity of H2252-035 is so similar to other CVs, Patterson and Price (1981) assert that the compact object must be a magnetic white dwarf and that this is an "unphase-locked" AM Her type system.

We present here the results of the HEAO A2 observation that first demonstrated the X-ray flux of H2252-035 to be pulsed and consider the possibility that the compact object in this system is a neutron star.

II. RESULTS

The HEAO A2[+] detectors (Rothschild et al. 1979) made a 6 hr pointed

[+]The A2 experiment on HEAO-1 is a collaborative effort led by E. Boldt of GSFC and G. Garmire of CIT, with collaborators at GSFC, CIT, JPL and UCB.

observation of H2252-035 on 1978 Dec 5, starting at 1600 hrs UT. Data from the Medium Energy Detector (MED, 2-15 keV) and High Energy Detector (HED, 2-60 keV) were searched using Fourier techniques for evidence of a periodicity. The power spectrum is shown in Figure 1 and a period at 805s (13.4 minutes) is clearly detected. The arrow indicates the optical pulse period of 858s. The two symmetric side lobes about the main peak represent the sampling pattern convolved with the power at the detected frequency and results from regular gaps in the data. The period we obtain is 805.14 ± 0.90s with (fitting a sine wave to the data) heliocentric maximum light occurring at JD2443848.32685 ± 0.00012. In Figure 1 the data folded modulo this period are shown in two different energy bands, 2-5 keV and 5-15 keV. There is a decrease in pulse

semi-amplitude from ~ 50% to ~ 25% with increasing energy and the semi-amplitude of ~ 90% seen between 0.1 and 4 keV by Patterson and Jablonski supports this trend.

The X-ray data were folded into 16 phase bins (1 bin ≈ one pulse period) about the orbital period using the ephemeris for maximum light from Patterson and Jablonski of JD2443808.682+0.149553E. 50% intensity variations from pulse to pulse were evident, but there was no evidence for any systematic trend associated with the orbital period. In particular there was no sign of any eclipse. Patterson and Jablonski have also reported a non-coherent periodicity in the optical flux at ~ 81s. We have searched for a corresponding modulation of the X-ray data and find none greater than ~ 5%. Scanning data were obtained for 3 five day observation intervals in December 1977, June 1978 and December 1978. The average intensity of the source for each observation was the same to within ~ 30%.

Spectral data from the MED and HED detectors were each summed over the entire pointed observation and tested against standard spectral models. A power law model of photon index ~ 1.4 or a thermal model with temperature > 20 keV were found to be equally acceptable. In both cases a 550 eV equivalent width iron line was required at ~ 6.7 keV. The best fitting spectra are given in Table 1 and the incident spectra, deconvolved using the best thermal fit, are shown in Figure 2. The distance to this source is estimated to be ~ 220 pc. by Patterson and Jablonski or between 100 and 750 pc by Hassall et al., giving an L_x of $4 \times 10^{32} \times (d/220\ \mathrm{pc})^2$ ergs s^{-1}.

III. DISCUSSION

Patterson and Price argue that the similarity of the L_x/L_{opt} of this system to that of other CVs indicates the compact object must be a magnetic white dwarf. Their line of reasoning is as follows. The optical light of CVs

is dominated by emission from the accretion disk, with the bolometric disk luminosity proportional to the mass accretion rate $\dot{M}_A$ (e.g. Bath, Pringle and Whelan 1980; Cordova, Mason and Nelson 1981). To obtain an X-ray luminosity of 10^{32} ergs s^{-1} from an accreting white dwarf requires an $\dot{M}_A$ of $\sim 10^{15}$ gm s^{-1}, which is at the lower limit of that generally seen from CVs (Warner 1976). The deeper potential well of a neutron star requires an $\dot{M}_A$ three orders of magnitude lower and makes the intrinsic light output from the disk trivial when compared to the X-ray luminosity i.e. a much larger L_x/L_{opt} would be expected.

If the variations in the optical light are attributed to reprocessed X-ray flux, then at least an average 5% and most probably 10% of the optical flux cannot come directly from the accretion disk. As already noted by Patterson and Jablonski and Hassall et al. the optical luminosity between 1200 and 7500 Å of 2.5 x 10^{-10} ergs s^{-1} is four times greater than the X-ray luminosity of 7 x 10^{-11} ergs s^{-1}. This means to meet the energy budget, the reprocessing material must intercept at least 25% of the X-ray flux, which is physically unreasonable. In view of the relative stability of the X-ray intensity over 1.5 yr this difficulty can only be avoided if there exists either a large unseen soft X-ray/far UV flux or the peak X-ray flux in the orbital plane is at least four times larger than we observe. <u>In either event, the need for this additional flux is independent of the nature of the compact object</u> and, apart from illuminating the secondary, will also light up the accretion disk. The argument for the compact object being a white dwarf, that is based on the similarity of the L_x/L_{opt} of H2252-035 to other CVs (Patterson and Price 1981), must be viewed with caution since the light from the disk may be totally due to reprocessed X-ray emission.

The X-ray properties (spectrum, pulse profile and luminosity) exhibit

little to distinguish it from the other X-ray pulsars that are believed to be rotating neutron stars. The hard X-ray spectrum with an iron line is typical of both neutron stars and magnetic white dwarfs. The fact that the pulse amplitude <u>increases</u> with decreasing energy is contrary to that seen in most neutron star pulsars although one, GX 301-4 does show such a trend (McClintock et al. 1977). While the intrinsic luminosity of this source of 10^{32} ergs s^{-1} is several orders of magnitude below the more typical values of 10^{35}-10^{38} ergs s^{-1}, there is one pulsar, X Per (3U0352+30), that has a similar luminosity and, coincidentally, a similar period (834s). Measurements of the period of this pulsar have demonstrated that it is decreasing with time and that the rate of decrease indicates the moment of inertia of the underlying body to be that of a neutron star (White, Mason and Sanford 1977). The current limit on $\dot{P}$ for H2252-035 of $< 9 \times 10^{-11}$ s.s^{-1} (Patterson and Price 1981) is not yet good enough to utilize this as a test for this source.

We can express the expected Alfven radius for a compact magnetic star (neutron star or white dwarf) as

$$r_a = 4 \times 10^9 \mu_{30}^{4/7} (M/M_o)^{1/7} L_{33}^{-2/7} R_6^{-2/7} \text{ cm}$$

where μ_{30} is the magnetic moment and R_6 the stellar radius (from Elsner and Lamb 1976). Typical neutron star values set the above parameters to unity and give $r_a \approx 4 \times 10^9$ cm. Approximately the same value for r_a is obtained for a magnetic white dwarf with a surface field of order 10^4 gauss. In either case this radius is similar to the inner disk radius obtained from the width of the Hβ emission by Patterson and Jablonski. Further, a Keplerian period of 81s about a 1.2 M_o star gives an orbital radius of 3×10^9 cm and it seems likely that the 81s non-coherent periodic oscillations reported by Patterson

and Jablonski result from inhomogeneities in the inner region of the disk (Bath 1973). These two points have the important implication that the Alfven radius is well within the co-rotation radius ($r_c = 1.5 \times 10^{10}$ cm) and gives a fastness parameter w_s, as defined by Ghosh and Lamb (1980), of 0.1 i.e. it is a slow rotator. This allows us to estimate $\dot{P}$, which from Ghosh and Lamb (1980) is

$$-\dot{P} = 6.0 \times 10^{-16} \, \mu_{30}^{2/7} \, R_6^{6/7} \left(\frac{M_x}{M_\odot}\right)^{-3/7} n(w_s) \, I_{45}^{-1} \left(P \, L_{33}^{3/7}\right)^2 \, s \, s^{-1}$$

where I_{45} is the moment of interia of the compact object in 10^{45} gm cm^2 (which $\sim$ 2 for a neutron star or $\sim 10^5$ for a white dwarf) and $n(w_s) \approx 1$ for w_s = 0.1. This gives $\dot{P} \approx -7 \times 10^{-11} \times \alpha$ s s^{-1} for $I_{45} = 2$, $M_x = 1.3$ and $L = 4 \times 10^{32} \times \alpha^{7/6}$ ergs s^{-1}, where $\alpha = (L/L_x)^{6/7}$ accounts for the unseen flux. This value of $\dot{P}$ is near the current upper limit to $\dot{P}$ for $\alpha = 4$. However, the uncertainties in the distance to the source and the physical parameters of the neutron star could change the predicted $\dot{P}$ by up to a factor 5 and a definitive test of the neutron star model requires a reduction in the observational uncertainty of $\dot{P}$ by at least an order of magnitude.

We thank Joe Patterson for providing his and other results in advance of publication.

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TABLE 1: H2252-035 SPECTRAL PARAMETERS (90% uncertainties)

	MED	HED
Normalization PL	0.0044	0.010
$\alpha+1$	1.4 ± 0.2	1.8 ± 0.3
N_H (H atoms cm^{-2})	$< 2 \times 10^{22}$	$(5\pm3) \times 10^{22}$
χ_r^2	1.0	0.9
Normalization Th	0.0014	0.0015
kT(keV)	$24^{+\infty}_{-4}$	$24^{+\infty}_{-8}$
N_H (H atoms cm^{-2})	$< 2 \times 10^{22}$	$(3 \pm 2) \times 10^{22}$
χ_r^2	1.1	0.9

LINE PARAMETERS

	MED	HED
Line Strength (phs cm^{-2} s^{-1})	$(1.6 \pm 0.8) \times 10^{-4}$	$(1.6 \pm 1.0) \times 10^{-4}$
L_{FWHM} (keV)	< 3	< 4
Energy (keV)	6.8 ± 0.2	6.5 ± 0.3
EW (eV)	560 ± 350	550 ± 450

$L_x = 6.7 \times 10^{-11}$ ergs cm^{-2} s^{-1} (0.5 - 50 keV)

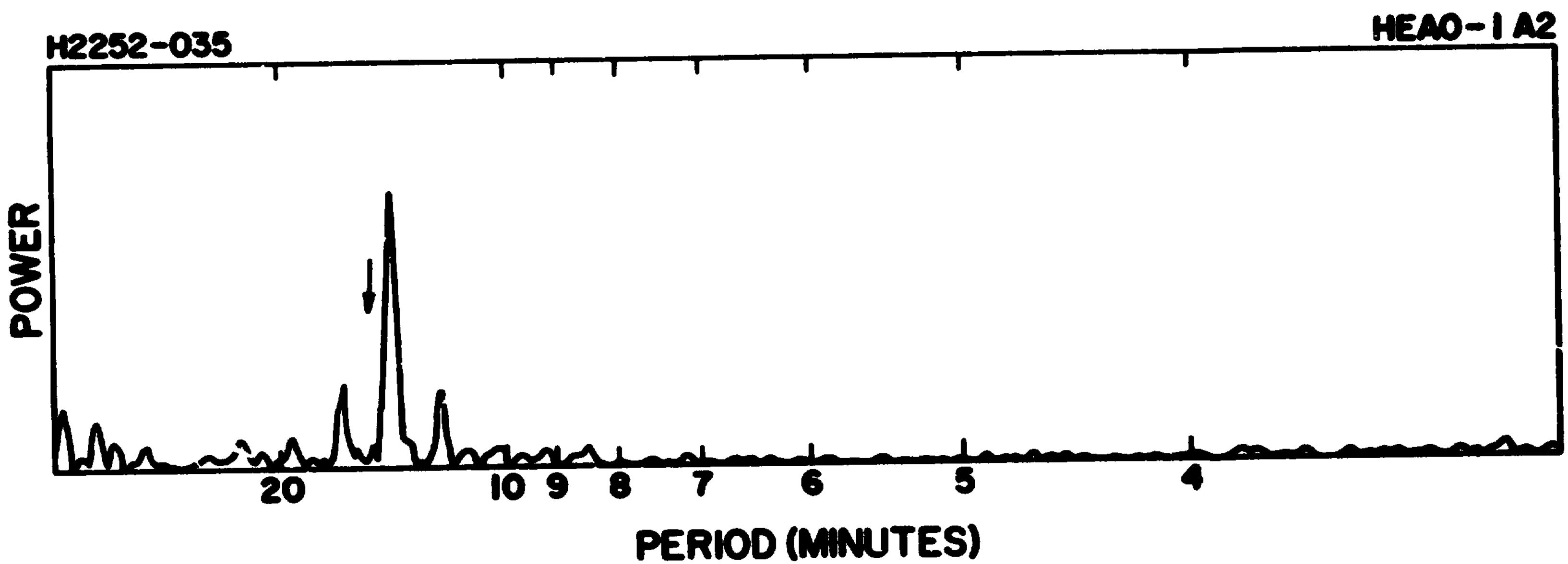
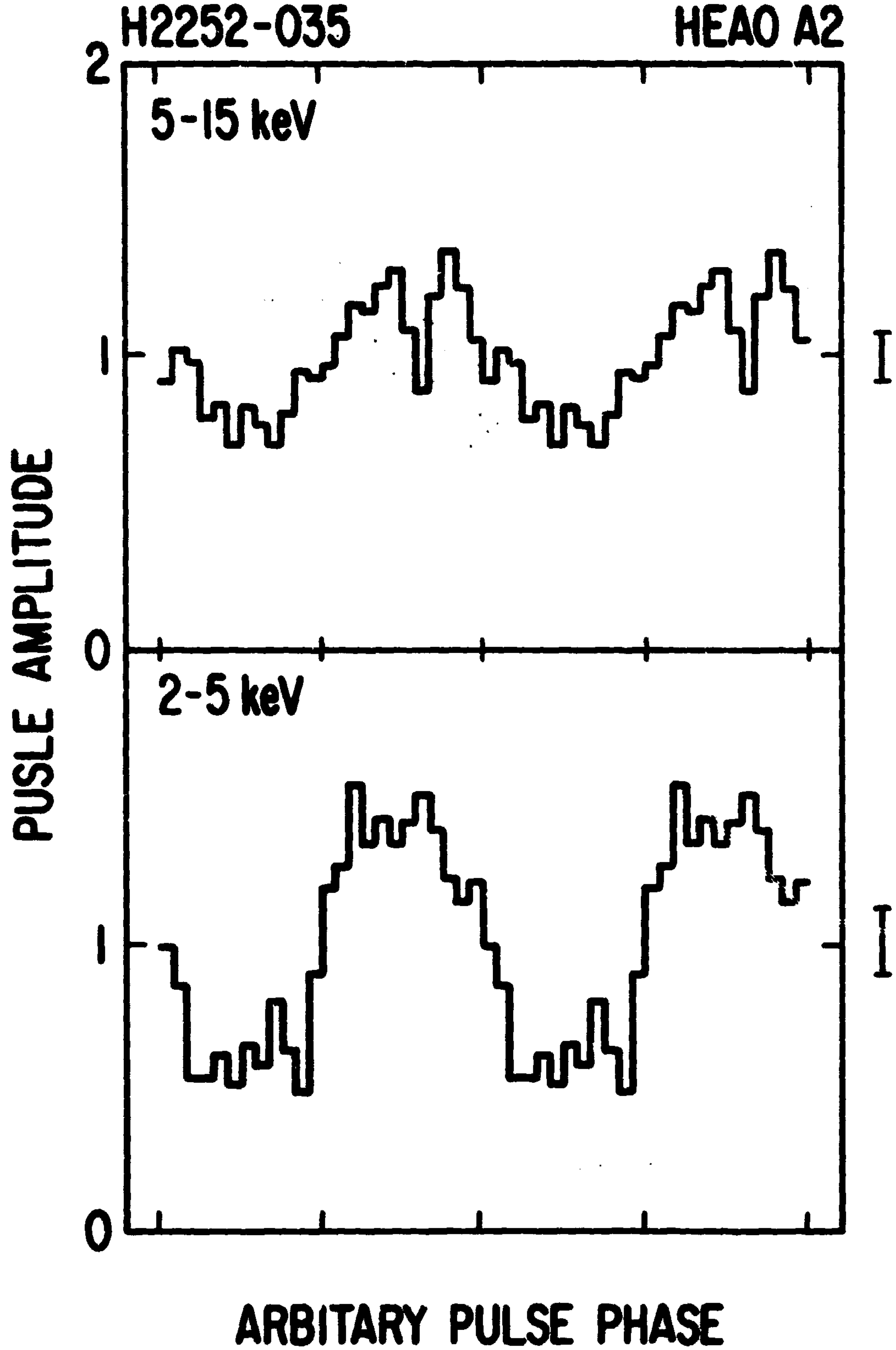

H2252-035
HEAO-1 A2
POWER
20
10
9
8
7
6
5
4
PERIOD (MINUTES)

FIGURE CAPTIONS

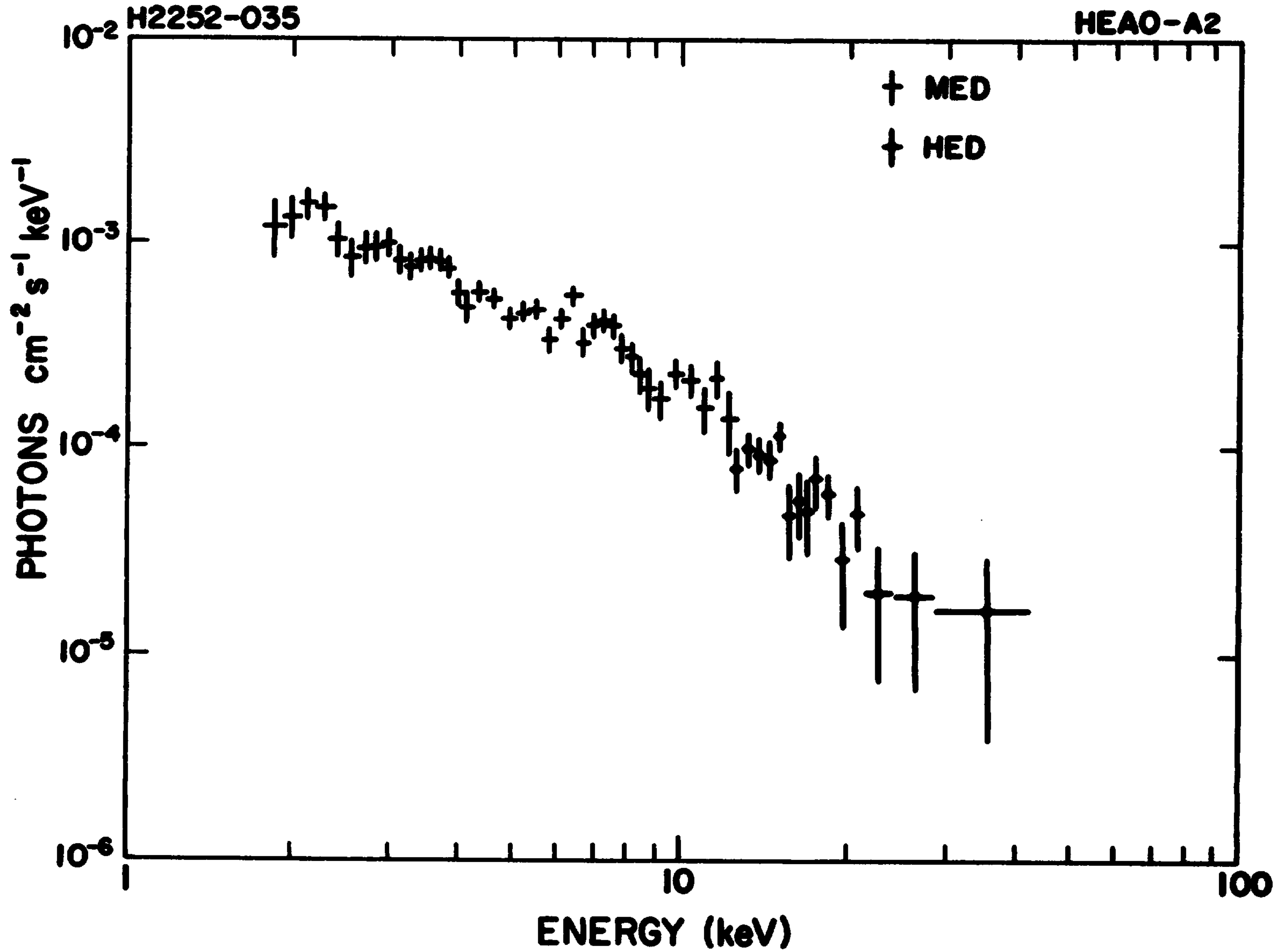
Figure 1 - The power spectrum of the sum of the MED and HED rates data. The arrow indicates the expected position of the 858s optical pulsation.

Figure 2 - The background subtracted pulse profile in two different energy bands normalized to the mean count rate. The plot has been repeated once for clarity. An arbitrary epoch of JD2443847.5 was used.

Figure 3 - The incident spectrum obtained when the best fitting thermal model is assumed.



H2252-035
HEAO A2
5-15 keV
2-5 keV
PUSLE AMPLITUDE
ARBITARY PULSE PHASE
2
1
0
1
0


H2252-035
HEAO-A2
MED
HED
PHOTONS $cm^{-2} s^{-1} keV^{-1}$
10^{-2}
10^{-3}
10^{-4}
10^{-5}
10^{-6}
1
10
100
ENERGY (keV)

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